Quantifying the Role of Physical Processes in Thin Layer Formation and Maintenance: Large Scale Physical Forcing of Thin Layer Dynamics

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LONG-TERM GOAL

Our long-term goal is to understand how physical mechanisms influence the formation, maintenance and dispersion of thin layers of phytoplankton and zooplankton. This understanding will help us to predict the frequency and occurrence of thin layers, as well as to identify other coastal regions that are favorable for thin layer development.

OBJECTIVES

Our first objective was to complete the processing of physical data from the '1998 Circulation Study' (24 May - 2 June), the '1998 Thin Layers Experiment' (June 10 - 25), and data supporting the 'NRL hyperspectral overflight' (continuous data 24 May to 8 August). Our second objective was to combine the processed data from 1998 with previously processed data from 1996 into a master statistical database. Our third objective was to use this master statistical database to investigate the impacts of physical forcing on thin layer dynamics. Our fourth objective was to complete manuscripts from this work. Our final objective was to make the physical data available to the oceanographic community.

APPROACH

We conducted a series of multidisciplinary cruises in East Sound, WA in 1996 and 1998. East Sound is a small fjord on Orcas Island in the San Juan Islands. In 1996 the purpose of these cruises was to test new instruments and deployment techniques utilized to quantify optical and acoustical thin layers. In 1998 a larger multidisciplinary experiment was undertaken to directly address the physical and biological mechanisms controlling thin layer dynamics. This experiment included the '1998 Circulation Study', the '1998 Thin Layers Experiment' and a cruise to support the ‘NRL hyperspectral overflight’.

WORK COMPLETED

(1) We have completed processing the physical data from the '1998 Circulation Study', the '1998 Thin Layers Experiment', and data supporting the 'NRL hyperspectral overflight'.

(2) We have completed a manuscript based on an analysis of the '1998 Circulation Study'.

- Dekshenieks MM, TR Osborn, PL Donaghay, JM Sullivan. submitted. Observations of general circulation patterns in East Sound, WA. Estuarine Coastal Shelf Sci.

(3) We have completed the development of the master statistical database. The master statistical database contains information regarding the biological attributes of each individual optical thin layer measured during the 1996 and 1998 experiments. The database also contains physical attributes (salinity, temperature, density, buoyancy frequency, shear and Richardson number) from the exact location of each thin layer. In addition, the database contains wind and tidal information, as well as the spatial relationship of each optical thin layer to the pycnocline.

(4) We are currently using the master statistical database to investigate the impacts of physical forcing on thin layer dynamics. We have two manuscripts that have resulted from this analysis (both are currently in press).

- Dekshenieks MM, PL Donaghay, JM Sullivan, JEB Rines, TR Osborn, MS Twardowski. in press. Temporal and Spatial Occurrence of Thin Phytoplankton Layers in Relation to Physical Processes. Mar. Ecol. Prog. Ser.
- Rines JEB, PL Donaghay, MM Dekshenieks, JM Sullivan, MS Twardowski. in press. Thin Layers and Camouflage: Hidden Pseduo-nitzschia populations in a fjord in the San Juan Islands, Washington, USA. Mar. Ecol. Prog. Ser.

(5) We have three additional manuscripts in preparation:

- Dekshenieks MM, TR Osborn, AE Gargett, PL Donaghay, JM Sullivan. in prep. The effect of pulses of low salinity water on circulation patterns in East Sound, WA. JGR
- Dekshenieks MM, PL Donaghay, TR Osborn, DV Holliday, JM Sullivan. in prep. Large scale forcing of thin layer dynamics. Mar. Ecol. Prog. Ser.
- Alldredge A, A Barnard, E Boss, J Case, T Cowles, MM Dekshenieks**, PL Donaghay, D Gifford, CF Greenlaw, C Herren, DV Holliday, D Johnson, D McGehee, S MacIntyre, MJ

Perry, JEB Rines, DC Smith, JM Sullivan, MS Twardowski, A Weidemann, JR Zaneveld. in prep. Changes in characteristic, distribution and persistence of thin layers over a 48-hour period. Mar. Ecol. Prog. Ser. (**paper coordinator)

(6) We have distributed the processed physical data to the Thin Layers group. This physical data is also available to the oceanographic community upon request.

RESULTS

Results from the '1998 Circulation Study' show that on a local scale, wind and tidal forcing are the primary processes influencing the circulation patterns in East Sound. The surface layer, which extends from 2 to 10 m, flows in the direction of the wind. Below the wind forced surface layer, the flow follows the tide in this 30 m deep Sound. In 1996, 71% of all thin layers were located at the pycnocline (between the wind forced surface layer and the tidally influenced sub-surface layer). Of the remaining 29% of the layers sampled, roughly 14% were below the pycnocline. These layers were frequently associated with advective processes within the system. The final 15% were sampled at times when density increased slowly and uniformly with depth, thus the pycnocline was not well defined. Buoyancy frequency, shear and Richardson number were calculated from physical measurements made at the exact location of each thin layer. Calculations show that thin layers occurred over a range of buoyancy frequencies (Figure 1a). Buoyancy frequency is a variable commonly used to indicate the strength of the density gradient in the water column. Roughly 40% of all thin layers were in regions of the water column where the buoyancy frequency was relatively low (less than 0.0005 $(\text{rads/s})^2$), while 60% of all thin layers were in regions of the water column with buoyancy frequencies greater than 0.0005 $(\text{rads/s})^2$. The layers in the regions of higher buoyancy frequency were most often associated with the pycnocline. Calculations also show that thin layers occurred over a range of shears (Figure 1b). There were two modes of distribution in the shear histogram. The first mode occurred at relatively low shears between 0 and 0.025 (s^{-1}) and the second mode occurred at moderate shears between 0.025 and 0.05 (s^{-1}). Only 5% of all thin layers were in regions of shear above 0.05 (s^{-1}). Finally, the Richardson number, which is the ratio of the buoyant restoring force to the shearing force, was calculated. Results show that no layers were found in regions where the Richardson number was less than 0.23 (Figure 1c). In general, regions of the water column where the Richardson number is below a value of 0.25 are unstable, and thus, would not be able to support thin layer development.

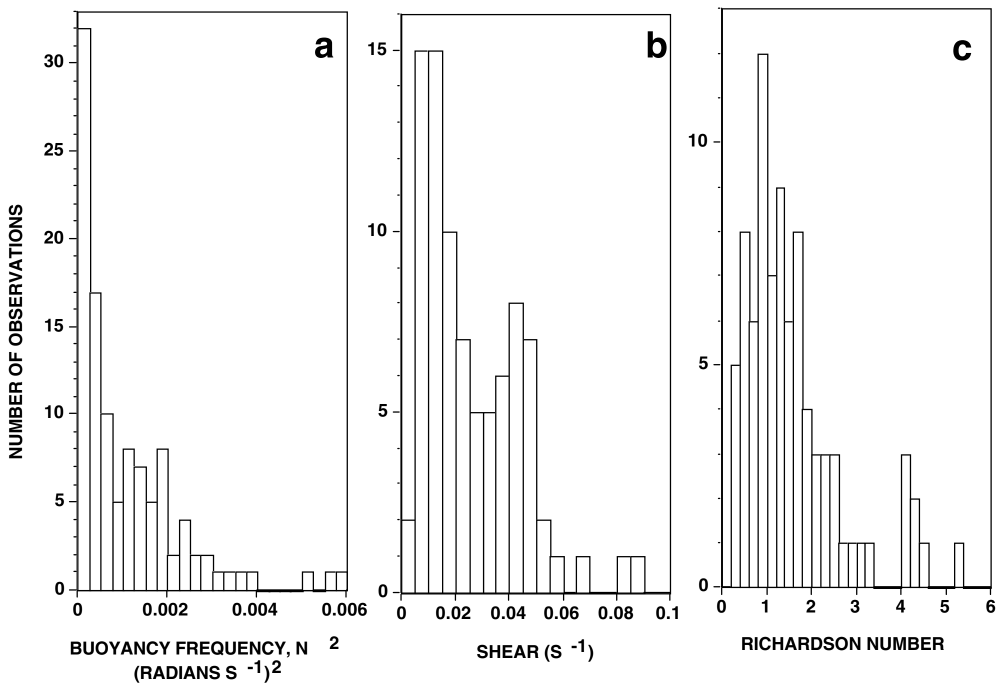

Figure 1: Histograms of; a) buoyancy frequency ((rads/s)^2), b) shear (s^{-1}), c) Richardson number. Buoyancy frequency, shear and Richardson number were calculated from physical measurements made at the exact location of each thin layer.

In addition to changes in local physical structure, the water mass 'type' in East Sound varies due to regional-scale winds, and tidal mixing occurring in the channels surrounding the San Juan Islands. The water mass 'type' in East Sound results from the mixture of water from two sources; warmer, lower salinity water from the Strait of Georgia and cooler, higher salinity, deep water from the Strait of Juan de Fuca (Redfield 1950). Pulses of lower salinity water are episodically advected at the surface from the Strait of Georgia through the channels surrounding the San Juan Islands into the Strait of Juan de Fuca. This occurs during the neap tide when tidal mixing is at a minimum. When winds are northwesterly, coincident with the neap tide, the amount of low salinity water being advected through the channels is significantly increased (Griffin and LeBlond 1990).

In 1998 between 24 May and 8 August, we recorded five distinct pulses of low salinity water in the East Sound. These low salinity pulses occurred during neap tides, 2 to 5 days following periods of northwesterly winds. The most pronounced pulses occurred from May to early July. The Fraser River, which empties into the Strait of Georgia, had its peak outflow during these months. The signal from each low salinity pulse can be detected in the Sound for 4 to 15 days, with an average of 7 days in duration. In general, the salinity drops in a relatively short time period, averaging 2.5 days, while it can take from 2 to 3 times that amount of time to raise the salinity to its original value. We have also observed that pulses of lower salinity water from the Strait of Georgia impact thin layer dynamics in East Sound. Thin layers of phytoplankton disappear during low salinity events. We hypothesize that the disappearance is due to several factors: First, thin layers are advected out of the Sound (along with the water that contains them) by the incoming fluid; Second, the layers are thinned due to the stretching by the shear which is forced by the incoming fluid. After the layers are thinned, they are mixed vertically; Third, the layers are pushed below the 1% light level and decay slowly. We believe the incoming water parcels are not rife with thin layers because they have very recently been subject to mixing in the channels surrounding the San Juan Islands, thus, there is little spatial heterogeneity in the source water. The re-formation of the thin layers occurs with restratifictaion of the water in East Sound. Restratification occurs first in the pycnocline and then in the lower regions of the water column. This process is a small part of the regional systems readjustment that occurs during the spring tide.

IMPACT/APPLICATION

Thin layers have important impacts on the biological structure and dynamics of marine systems, as well as on the optical and acoustical properties of those systems. As a result, it is critical that we develop techniques to detect such structures and to predict their dynamics. The strong statistical relationship between thin layers and physical structure as well as theoretical arguments (Donaghay and Osborn 1997, Osborn 1998) indicate that we cannot understand thin layer dynamics without understanding physical forcing and bio-physical interactions at both small and large scales.

TRANSITIONS

The software developed for this project has been transitioned for use in the Ocean Response Coastal Analysis System (ORCAS) autonomous underwater profilers. This project involves partners at the Naval Research Laboratory (Stennis), and the Naval Oceanographic and Meteorological Command. This project was funded under the National Ocean Partnership Program (NOPP).

RELATED PROJECTS

This research provides PIs in the 'Thin Layers Program' with a larger context of physical circulation, within which the finescale and microscale biological and physical processes that control thin layer dynamics may be addressed. Clearly, in order to interpret small scale patterns in biological distribution, it is necessary to understand the larger scale circulation patterns. Related projects include; (1) Alice Alldredge and Sally MacIntyre (UCSB) are investigating patterns of thin layers of marine snow, and how these patterns are related to turbulent microstructure in East Sound, (2) Tim Cowles (OSU) is investigating how interactions between small-scale physical, optical and biological processes contribute to the formation of thin layers of phytoplankton in East Sound, (3) Percy Donaghay (URI) is investigating how both biological and physical process contribute to the temporal and spatial patterns of thin layers of phytoplankton and zooplankton in East Sound, (4) Dian Gifford (URI) is studying grazing processes and the structure and persistence of thin biological layers in East Sound, (5) Van Holliday, Charles Greenlaw, Duncan McGehee (BAE Systems) and Rick Pieper (USC) are using new acoustical technology for the study of thin layers of zooplankton, (6) Mary Jane Perry (UMaine) is investigating the mechanisms responsible for the variability in phytoplankton biomass and primary production of thin layers in East Sound, (7) Jan Rines (URI) is studying the interactions of small-scale physical mixing processes with the structure, morphology and bloom dynamics of non-spheroid diatoms leading to thin layers, (8) Ron Zaneveld and Scott Pegau (OSU) are investigating the physical and optical characteristics of thin layers in East Sound.

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PUBLICATIONS

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